HEAT TRANSFER IN FLUIDIZED BEDS OF SMALL PARTICLES

BY

ROBERT DANIEL TOOMEY

B.S., University of Washington, 1945
M.S., University of Washington, 1946

AN ABSTRACT OF A THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
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Introduction

Fluidization is a new industrial method for obtaining intimate contact between fluids and solids. Several investigators (2) (5) (7) (8) have correlated fluidization variables either by empirical means or by using dimensionless groups or fixed bed relationships without analyzing the true forces within a fluid bed. Bowman (1) has approached the problem in a theoretical manner, but his results are not sufficiently advanced to predict process variables. Leva (3) investigated heat transfer to the walls of a fluid bed and, after considering certain relationships, derived a simple equation which fit his data. Mickley and Trilling (6) reported the heat transfer characteristics of two columns, one heated internally and the other heated externally and correlated their data empirically. Levenspiel and Walton (4) presented heat transfer rates between a bed of pulverized coal and the outside wall.

The object of this investigation was to study the heat transfer coefficients at the containing walls of fluid beds and, if possible, to explain the mechanism of heat transfer and the effect of different variables. In considering the variables which affect heat transfer, a mechanism of fluidization was conceived which is presented as a part of this thesis.

Experimental

The fluidized bed was supported by a flat porous plate in a five inch i.d. column. In all runs, spherical glass beads were fluidized in an air stream. The walls of the column were constructed by placing annular tanks, five inches high, one above the other and insulating these from one another with one inch sections of transite. These sections formed a smooth inner wall. The proper water connections were made to each tank so that the heat was transferred to a measured volume

of water and local coefficients could be measured. A Calrod heating element was placed in the center of the column. Over sixty thermocouples were placed in the column to measure gas, bed, wall, water, and Calrod tempeatures, and hence heat transfer coefficients at the Calrod and at the wall could be calculated. A five-sided prism was set in each section of transite with one side flush with the inner wall. High speed motion pictures of the moving bed were taken through these prisms. From these the particle velocities at the wall were measured.

Theory

A theory of fluidization based on two major postulates is proposed which is useful in explaining empirical correlations and observed effects, both in the mechanism of fluidization and in heat transfer to boundary surfaces in fluid systems. The first postulate considers that a fluidized system is composed of two phases, one consisting of uniformly distributed particles in a supporting gas stream, and the other consisting of pure gas in the form of bubbles, channels, or slugs. The second postulate proposes that the product of the effective velocity and viscosity is proportional to the particle diameter squared. Experimental data show that the effective velocity is proportional to $Dp^{0.5}$ and the effective viscosity is proportional to $Dp^{1.5}$. If this is so, the effective Reynolds number and the drag coefficint are relatively constant for all fluidized systems.

An analysis of the gas flow through the voids of the phase containing the solids substantiates these postulates, as does the following equation which was derived theoretically from three separate considerations of energy transformations based on the above postulates;

$$\log\ (G/G_{mf}) = 1/A\ (KD_p^{0.5} - k)\ \Delta P_{ke}/\Delta P_{mf},$$

where G is the mass velocity of the gas stream, G_{mf} is the mass velocity at incipient fluidization, A is the area of the column, D_p is the particle diameter, ΔP_{ke} is the additional ΔP

above ΔP_{mf}, ΔP_{mf} is the pressure drop at incipient fluidization, and K and k are constants. Data taken on the particle movement and the empirical relationships presented by Lewis (5) help verify the above postulates.

Heat Transfer Correlations

The heat transfer coefficients at the wall are correlated by plotting a modified Nusselt number versus a modified Reynolds number using particle velocity and particle diameter. This correlation indicates that particle velocity is an important factor in determining the value of the heat transfer coefficient. From a different approach the coefficients are also correlated in the following equation with three dimensionless groups, the modified Nusselt number, a modified Reynolds number using the gas velocity at incipient fluidization, and the ratio of the gas velocity to the gas velocity at incipient fluidization

$$\log (hD_p/k) = 0.517 \log [D_p V_{mf} \rho_g/\mu_g (\log G/G_{mf})] + 0.66$$

This correlation shows that the heat transfer coefficients are functions of the particle velocity and the Reynolds number for the flow through the void spaces adjacent to the heat transfer surface, as well as substantiates the previous concepts of fluidization.

The coefficients at the internal heater were usually considerably higher than those at the wall and often shifted in the opposite direction to those at the wall when external conditions were changed. These differences could be explained by the previous concepts of fluidization. The range of the average coefficient for the second and third sections was 22.7 to 88.6 Btu/(hr.) (sq. ft.) (°F) at the wall and 47.5 to 135 Btu/(hr.) (sq. ft.) (°F) at the Calrod.

Channeling is detrimental to heat transfer, but slug flow does not seem to affect the heat transfer until it exposes an appreciable amount of surface to the pure gas phase. The depth of the bed was found to affect the heat transfer, because

it partially controls the particle movement, while temperature level was found to have only a slight effect over the range studied, and this was probably due to a change in heat transfer by radiation. Also, over the range studied, mixtures were found to have only a slight effect on the heat transfer characteristics.

Summary

A theory of fluidization is presented which is based on a consideration of forces and energies within fluidized systems. Both the previous data and the results of this investigation indicate that the postulates used are at least good first approximations. Further refinement is needed under certain conditions of flow. The available data stress the importance of particle flow patterns which are sensitive to many variables. The values of heat transfer coefficients are largely controlled by the particle flow and particle diameter, and the variations of these coefficients as well as discrepancies between investigators are predicted and explained in this thesis.

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VITA

The author was born on April 3, 1923, in Portland, Oregon. After graduating from Grant High School in Portland in 1941, he entered the University of Portland holding two scholarships, one from the Oregon Journal and the other from the University of Portland. During the following three years he attended Oregon State College, Catholic University of America, and the University of Washington, majoring in chemical engineering at each school. He graduated from the University of Washington in 1945 with the Bachelor of Science Degree in Chemical Engineering. He then held a State of Washington research fellowship for one year and received the Master of Science Degree in Chemical Engineering in 1946. Since that time he has been completing the requirements for the Degree of Doctor of Philosophy in Chemical Engineering at the University of Illinois. He held a teaching assistantship his first year at Illinois and the Pittsburgh Consolidation Coal Company fellowship for two years. During this period one summer was spent in the process design division of California Research Corporation. He is a member of Tau Beta Pi, Sigma Xi, Phi Lambda Upsilon, and Gamma Alpha.